

AN ECONOMIC HYDROPOWER SCHEME FOR LOW-HEAD SITES, USING A SIPHON SYSTEM

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Abstract: This paper describes an economic means of converting energy from a low-head hydro source, using siphons to convert from water to air pressure.(more)

1 Introduction

The majority of the world's most economic sites for hydro power have already been exploited. They provide clean energy amounting to approximately 5% of world total energy consumption. But there is still a large remaining hydro resource, estimated at 7000 TWh per year, or roughly a further 5% of total world energy consumption. Much of this is at low heads, on rivers descending slowly through foothills and lowlands. Small, low-head hydro sites are increasingly favoured, because of their small environmental and social impact, but exploiting them with conventional hydro plant is often found to be marginally economic, at best; indeed, such sites may go unused for this very reason. If a less costly type of hydro plant could be used to convert the hydro energy at these sites, this would help to reduce consumption of fossil fuels and to cut greenhouse gas emissions.

The siphon hydro system described in this paper is relatively inexpensive to install, especially where there are weirs already in place.

2 The siphon hydro system

A weir on a river is bridged by one or more siphon tubes which carry water continuously from the upper reach to the lower (Fig.1). As they pass over the weir, the tubes are well above the water levels. Consequently, the pressure within them is less than atmospheric pressure.

Aerators A near the top of the downward legs of the tubes admit air, which is carried downwards in the form of bubbles. So long as the downward water speed is greater than the rate at which the bubbles rise relative to the water, the bubbles are carried down, and the air escapes at the outlet into the lower reach of the river.

Thus, the siphon draws air steadily from atmospheric pressure at the inlet to the lower pressure at the aerator. This pressure difference is sufficient to drive an air turbine.

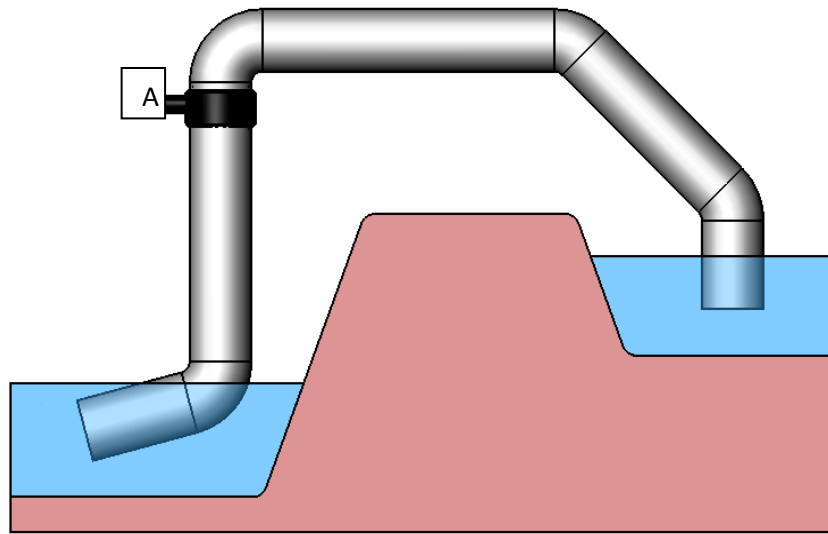


Fig. 1. Siphon system

The turbine can be installed at a convenient location on dry land; air is drawn into the turbine inlet directly from the atmosphere, and the turbine exhaust is connected by suitable pipework to the siphon aerators.

2.1 Principles of operation of the system

The head between the water levels on the upstream and downstream sides of the weir is H . However, the whole of this head is not available to drive water through the siphon, because the downward leg is aerated, and so its density is less than that of water. This reduction of the driving head we have called the buoyancy head, denoted by the symbol B . The net driving head is thus $(H - B)$.

The remainder of this net head is used in overcoming friction loss in the pipes, together with other losses, including entry loss and exit loss. All of these losses are proportional to u^2 , so the overall head loss can be represented as $K(u^2/2g)$, where K is a friction loss coefficient.

Bringing these facts together, we obtain the governing equation of the siphon:

$$H = B + K(u^2/2g) \quad (1)$$

Here H is the driving head: the difference in the levels of the water upstream and downstream of the weir. The buoyancy head, B , is the part of the original water head that is useful in pumping the air. The third term, $K(u^2/2g)$, is the part of the original head that is wasted in losses, at entry, due to pipe friction, and at the exit - obviously it is desirable to minimise these losses, so that as much as possible of the driving head H is available for the air-pumping operation. This requires careful design of the pipework to have a smooth interior surface without steps or sudden

changes; ideally a diffuser at the outlet, or at least a bell-mouth; and a radiused inlet. The bends should be swept long-radius bends.

An expression for the buoyancy head, derived in [French and Widden; Howie and Pullen], is given as

$$B = x_A \left(\frac{1}{r} \ln r \right) \frac{p_C}{\rho g} \quad (2)$$

In this expression, x_A is the ratio by volume of air to water at the aerator; p_C is the absolute pressure at the siphon outlet; r is the pressure ratio p_C/p_A , where p_A is the absolute pressure at the aerator; ρ is the density of the water, and g is the acceleration of gravity.

2.2 Efficiency

Regarded as a converter of energy from the gravitational potential energy of the river water to the energy of the pumped air, the system has the following losses:

- Losses proportional to u^2 , as set out in equation (1)
- Losses due to the upward drift of the bubbles
- Energy used to create the bubbles in the water.

The first of these is reduced by careful design of the flow passages, and by keeping the flow speed u of the water to a low value. However, the loss due to upward drift of the air bubbles increases as the flow speed u is reduced. There is an optimum flow speed, at which the sum of the friction losses and drift losses is minimised.

[[[Something here about energy to create bubbles....]]]

For the efficiency of the whole plant, it is necessary to include the efficiency of the turbine and generator in the calculation.

In order to maintain stable bubbly flow in the downward leg of the siphon and so to carry air through the system continuously, the void fraction (the fraction of the total volume occupied by air) needs to be kept below approximately 0.3 [Wallis, 1969]. Above this value, the pattern tends to change to slug flow, so breaking the siphon.

The bubbles rise relative to the water at a speed which varies slightly with bubble diameter, but over the range of conditions likely to occur in the siphon the relative speed has been found to be approximately 0.24 m/s [Rice, 1976]. This drift, or slip, of the bubbles represents an energy loss.

[Next: experimental work, aerator designs, etc...
Lab rig; student project at Sandall with photo.

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